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THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

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MARCH and JUNE, 1950

NITRITE POISONING OF PIGS.

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SUMMARY.

Heavy mortality in pigs fed on soup prepared by cooking beef and offal in well water was investigated on two farms. The well water on each farm had a high nitrate content, equivalent to 2970 and 1740 p.p.m. expressed as sodium nitrate. Batches of these soups which were analysed contained nitrites equivalent to 1127 and 393·6 p.p.m. sodium nitrite.

It is considered that the mortality which occurred in pigs on these farms was due to nitrite poisoning and that the nitrite was derived from the nitrate in the well waters.

The toxicity of sodium nitrite for pigs was observed by dosing after 18 hours fasting with a 1 per cent. aqueous solution. Doses of 0·05, 0·06, 0·07, and 0·08 gm. sodium nitrate per kgm. body weight produced moderate to severe non-fatal methaemoglobinaemia. Two pigs weighing 61 and 80 kgm. died two hours after they had been dosed at the rate of 0·09 gm. per kgm.

Soups were prepared in the laboratory by boiling beef, bones and meat scraps in well water from one of the affected farms. The water contained nitrates equivalent to over 2300 p.p.m. sodium nitrate and nitrites equivalent to less than 10 p.p.m. sodium nitrite. In two trials soups containing 1430 and 1245 p.p.m. sodium nitrite were obtained.

INTRODUCTION.

The ability of ingested nitrite to reduce haemoglobin to methaemoglobin and thus to impair the oxygen capacity of the blood has long been known. Toxic symptoms appear when about 50 per cent. of the haemoglobin has been reduced to methaemoglobin (Nicholson, 1945).

Poisoning of cattle by oaten hay containing nitrate was described by Bradley, Eppson and Beath (1940) and Davidson, Doughty and Bolton (1941). Williams and Hines (1940) showed that the toxicity of the plant *Salvia reflexa* (mint weed) is due to nitrate. The nitrate is reduced by enzymes in the plant or in the rumen or liver of the animal to the more toxic nitrite. Gwatkin and Plummer (1940) showed that pigs dosed, after 24 hours' starvation, with potassium nitrate solution at the rate of 2·5 gm. of the salt per kgm. body weight suffered no ill effects, while 3·7 gm. per kgm. was fatal. Potassium nitrite given under similar conditions was much more toxic, as little as 0·25 gm. per kgm. being fatal.

McIntosh, Nielson and Robinson (1943) showed that the toxicity of cooked mangels fed to pigs was due to the presence of nitrite. They found that, to prevent the formation of toxic amounts of nitrite, it was necessary to cook the mangels at or near 100 deg. C. for at least two hours. McIntosh (1950) states that in this work mangels containing 6050-7360 p.p.m. sodium nitrate were cooked in a town water supply which, though not tested, probably contained minute traces only of either nitrate or nitrite.

In Queensland, at various times, heavy mortality has occurred in pigs fed cooked vegetables (most often pumpkin or mangels) or cooked meat or offal. None of the cases in which cooked vegetables were implicated has been investigated with nitrite poisoning in mind, but the New Zealand work of McIntosh *et al.* suggests that these Queensland outbreaks might have been due to nitrite poisoning.

The observations reported here relate to poisoning caused by soup made from boiled meat and offal. On two farms where detailed observations were made it was found that the water in which the offal was boiled had a high nitrate content. When offal was boiled in these waters nitrite was produced in amounts sufficient to render the food toxic to pigs.

Observations are recorded here on:—

(1) Natural outbreaks of nitrite poisoning in pigs fed on cooked offal.

(2) The toxicity of sodium nitrite for pigs.

(3) The toxicity of cooked offal prepared experimentally with well water which had a high nitrate content.

METHODS OF ANALYSIS.

Nitrates were determined by a modification of Ulsch's method in which nitrate was converted to ammonia with sulphuric acid and reduced iron, the ammonia being distilled by the usual Kjeldahl method, using magnesium oxide instead of sodium hydroxide to liberate ammonia. Devarda's alloy was not available for the reduction.

Nitrites were estimated by 1940 AOAC methods of analysis (Association of Official Agricultural Chemists, 1940).

Nitrate and nitrite levels are expressed throughout as the equivalents in parts per million of sodium nitrate and sodium nitrite respectively.

Haemoglobin determinations were made by J. M. Harvey in the Department's Chemical Laboratory by measuring the oxygen capacity of the blood in a Van Slyke manometric gas analysis apparatus.

CASE REPORTS.

Farm A (Beaudesert District).

This herd was fed on boiled slaughteryard offal, bones and meat scraps (mostly beef). Water was obtained from two sources—an earthen tank (or dam) and a well 135 feet deep. There was a local belief that pigs could not be fattened at this piggery owing to the toxicity of the well water. Consequently the owner, a butcher, used the piggery only when he had an excess of offal. Further, he did not use the well water unless the dam was dry. The offal was cooked principally to secure the tallow.

Information from the owner showed that in 1945 the dam dried up and offal was boiled in well water and fed to the pigs. Six pigs died during the following week and pig fattening was then abandoned for some months.

About April, 1946, he again penned pigs for fattening and used water from the dam to boil the offal. No sickness or deaths occurred. By July 1 the dam was empty and well water was brought into use. The herd appeared healthy at feeding time on the evening of July 6, but on the following morning 16 of a herd of about 30 were dead. Analyses of samples submitted by the local Inspector of Stock showed that no arsenic or heavy metals were present in the stomach contents and that the waters were low in total chlorides.

As butcher's offal was used it was suspected that beef pickled with nitrate may have been included in the offal. Analysis confirmed nitrite in all specimens, as follows:—

Well water—8·9 p.p.m. sodium nitrite.

Well water stored in iron tank—69·0 p.p.m. sodium nitrite.

Stomach contents of dead pig—3·0 p.p.m. sodium nitrite.

The water samples were received in 1 lb. glass jars with metal screw caps. The nitrites in the sample from the iron tank rose in a few days from 69 p.p.m. to 189 p.p.m., and later to 234 p.p.m. Nitrates were present in large quantities, viz., 2888 and 2324 p.p.m. sodium nitrate in the well and tank waters respectively.

The piggery was visited on July 19, 1946, to observe the boiling processes and to examine the possibility of the nitrate in the well water being derived from contamination of the well by refuse. It was found that the position of the well precluded external contamination. Field tests showed that the nitrites were higher in well water stored in a 400-gallon iron tank than in the water as it was pumped from the well. The dam water was free from nitrite. Laboratory analyses (Table 1) showed that the total chlorides calculated as sodium chloride were the same in both waters (viz., 761 p.p.m.), indicating that the increase in nitrite was not due to evaporation. Two batches of soup composed of offal, bones

Table 1.

Chemical Analyses of Samples Collected at Farm A.

Date.	Sample.	$NaNO_2$ p.p.m.	$NaNO_3$ p.p.m.	NaCl p.p.m.
July, 1946 ..	Well water direct from delivery pipe of pump*	6·1	2970	761
	Well water stored in iron tank	41·6	2890	761
	Soup during boiling	1127	..	..
	Soup cooled and tallow removed ready for feeding	1225	..	..
July, 1947 ..	Well water direct from delivery pipe of pump	5·0	1970	569
	Well water stored in iron tank	100	2110	627
	Soup ready for feeding	2·5	trace	..
	Dam water being used for preparation of soup	nil	nil	..

* All samples were taken in glass bottles with cork stoppers and were filled to leave no air-space.

and beef scraps were also high in nitrite. A batch which had been boiling for several hours and was still boiling when sampled contained 1127 p.p.m. sodium nitrite. A soup which had cooled and from which the tallow had been skimmed contained 1225 p.p.m. sodium nitrite.

The herd was being fed entirely on cooked offal diluted with an equal part of dam water, so that the final nitrite content would be 500-600 p.p.m. sodium nitrite (500 p.p.m. = 35 grains per gallon).

There had been no deaths from July 7 until the afternoon before the visit, when one pig died. A post-mortem examination was done on this animal about 18 hours after death, but the carcase was so decomposed as to be of little value. The liver contained 2·9 p.p.m. and the stomach content 7·8 p.p.m. sodium nitrite.

Experiments reported below showed that 0·09 gm. sodium nitrite per kgm. body weight may kill pigs. The pigs on farm A weighed about 45 kgm., hence 8·1 litres of a soup containing 500 p.p.m. sodium nitrite could be fatal to such animals. As no other feed was given it is likely that this amount of soup would be consumed.

The nitrite in the cooked offal was evidently derived from the nitrate in the well water. It will be noticed that some nitrite was produced during the storage in the iron tank and that a great increase in nitrite occurred when the water was boiled with meat in large iron vessels over wood fires.

Heavy rain (18·17 inches) fell between January 18 and February 1, 1947. On February 10 the well water contained 9·5 p.p.m. sodium nitrite and 2433 p.p.m. sodium nitrate, indicating very little dilution by the heavy rain. On February 26 the well water contained 8·4 p.p.m. sodium nitrite and 2331 p.p.m. sodium nitrate. The well was still high in nitrate (1970 p.p.m.) in July, 1947, and soup being prepared at that time with dam water contained only negligible nitrite, viz., 2·5 p.p.m. (Table 1).

Farm B (Pittsworth District).

This herd consisted of 80 mixed pigs fed on whey, crushed sorghum, wheat, barley and wheaten or lucerne hay. On August 9, 1946, beef scraps were boiled in water pumped from a deep bore and fed to pigs. Each day thereafter this beef-soup was reboiled in well water and some was fed. On August 12, 14 store pigs 3-5 months old died within 2½ hours of feeding. Analyses of samples collected on the day of this mortality by the local Inspector of Stock resulted as follows:—

Bore water—1740 p.p.m. sodium nitrate;
0·37 p.p.m. sodium nitrite.

Beef soup—1690 p.p.m. sodium nitrate;
393·6 p.p.m. sodium nitrite.

Stomach contents of dead pig—4·9 p.p.m. sodium nitrite.

Inflammation of the gastric mucosa, with many haemorrhages from pin-point up to 2 cm. in diameter, was found in a dead pig examined by the Inspector of Stock. No other lesions were noticed. The characteristic feature of nitrite poisoning is the brown colour imparted to the blood by methaemoglobin, but this may disappear a few hours after death.

It will be noted that the beef soup was boiled three times before deaths occurred. The final product contained 393·6 p.p.m. (28 grains per gallon) sodium nitrite. Assuming that these pigs weighed 25 kgm. and that 0·09 gm. of sodium nitrite per kgm. body weight constitutes a fatal dose, then about 5½ litres of this beef soup would be fatal. McIntosh *et al.* (1943) stated that boiled mangels containing 20 grains sodium nitrite per gallon (i.e. 286 p.p.m.) are dangerous to small pigs.

THE TOXICITY OF SODIUM NITRITE.

Pigs varying in weight from 48 to 80 kgm. were dosed experimentally with sodium nitrite. The experimental animals were in good condition and had been fed in pens on crushed grain containing about 9 per cent. meatmeal and 10 per cent. lucerne chaff for several weeks before they were used. The morning feed was omitted on the day the pigs were dosed. A small feed of crushed grain was given about two hours after treatment. The results are summarized in Table 2.

Table 2.

EFFECT ON PIGS OF 1% SOLUTION OF SODIUM NITRITE GIVEN BY STOMACH TUBE.

Dose Rate gm./kgm.	Animal No.	Weight kgm.	Haemoglobin (gm. per 100 ml.)			Results.
			Pre-treatment.	3 hr.	5 hr.	
0·04	487	73	..	..	..	Non-fatal methaemoglobinaemia 2–4 hours after treatment. Recovered in 6–7 hours
0·045	581 (capsule)	73	..	..	..	
0·045	485	66	..	..	..	
	486 (capsule)	73	14·6	9·4	13·0	
0·05	484	53	14·2	8·7	11·3	
0·06	488	48	..	..	..	
0·07	488	51	..	..	..	Severe non-fatal methaemoglobinaemia 2–4 hours after treatment. Recovery in 7 hours
0·08	487	75	..	..	..	
0·09	484	61	..	..	..	Dead in 2 hours
	486	80	..	..	..	

The effect of sodium nitrite given in the solid form in gelatin capsules was compared with the effect of a 1 per cent. aqueous solution given by stomach tube. A pig dosed by capsule developed similar, but slightly less intense, symptoms to those shown by a pig dosed with a 1 per cent. solution at the same dose rate—viz., 0·04 gm. sodium nitrite per kgm. body weight. At a dose rate of 0·045 gm. per kgm., administration by capsule and stomach tube produced symptoms which were similar in intensity and in the time of their development and eventual disappearance. Subsequent observations were made by dosing by stomach tube with the 1 per cent. solution.

The lowest dose rate used—viz., 0·04 gm. per kgm.—produced definite symptoms of methaemoglobinaemia. About two hours after treatment the skin over the whole body was blanched. The pigs became docile and lethargic but they ran normally when chased. The conjunctival vessels were a definite nut-brown colour. About five hours after treatment these symptoms had disappeared and the animals appeared normal.

Single pigs were then dosed with 0·05, 0·06, 0·07, and 0·08 gm. per kgm. Symptoms of methaemoglobinaemia developed in all cases and became more severe as the dose rate was increased, but none of these doses was fatal. Symptoms were at their height three to four hours after treatment. Blanching of the skin was the first visible symptom, and it was easily seen when there were treated and untreated pigs in the same pen. (All the experimental pigs were Large Whites.) The higher dose rates produced methaemoglobinaemia, which was so marked that distinctly coffee-coloured blood was visible in the conjunctival vessels. Respiration became rapid and shallow and the pigs were very disinclined to exert themselves.

Two pigs weighing 61 and 80 kgm. were then dosed at the rate of 0·09 gm. per kgm. Both pigs developed severe methamoglobinaemia and died two hours after treatment. There was no struggling until about five minutes before death.

Autopsy immediately after death of the two fatal cases revealed similar lesions in each animal. The subcutaneous blood vessels were engorged with chocolate-coloured blood. The heart was in diastole. The lungs were pale and contracted and approximately 20 sub-pleural petechiae were found about the hilus of each organ. Congestion and petechiation was noted on the glandular mucosa of each stomach. The duodenum was catarrhal but the remainder of the small and large intestines of each pig appeared normal. The livers and kidneys were greatly engorged with chocolate-coloured blood and the spleens were contracted. Liver, kidneys, urine and contents of the alimentary tract of these two pigs were analysed for nitrite. The results of these analyses are shown in Table 3.

Table 3.

PIGS DOSED WITH 1% SOLUTION SODIUM NITRITE: SODIUM NITRITE CONTENT OF ORGANS FROM FATAL CASES.

Pig No.	Specimen.	Total Weight gm.	Weight of Sample gm.	$NaNO_2$ p.p.m.
484	Stomach content	566	566	887
	Small intestinal content	336	336	2·96
	Large intestinal content	not weighed	762	3·45
	Liver	1816	681	less than 1
	Two kidneys	227	227	less than 1
	Urine	about 100	..	less than 1
486	Stomach content	1589	1589	250
	Small intestinal content	364	364	4·0
	Large intestinal content	3458	790	3·2
	Liver	2000	454	less than 1
	Two kidneys	252	252	less than 1
	Urine	nil	nil	..

EXPERIMENTS WITH COOKED OFFAL.

Observations were made on the nitrite and nitrate content of beef soups prepared experimentally with well water from farm A. The toxicity of the soup was tested by feeding it to pigs.

The soup was made by boiling beef scraps (30 lb.), usually rib and shin bones and a head, for four to five hours in well water. The vessels used were an iron petrol drum (44 gallons) and a kerosene tin. The latter was a 4-gallon iron vessel coated with tin by dip galvanizing.

Table 4.

NITRITE CONTENT OF SOUPS PREPARED BY BOILING BONES AND OFFAL IN WELL WATER FROM FARM A.

Trial.	Treatment.	Vessel.	$NaNO_2$ p.p.m.
1	First boiling	Iron drum	..
	Second boiling	Iron drum	..
	Third boiling	Iron drum	..
	Fourth boiling	Kerosene tin	720
2	First boiling	Iron drum	258·8
	Second boiling	Iron drum	241·6
	Third boiling	Iron drum	156·0
	Fourth boiling	Kerosene tin	1060·0
	Fifth boiling	Kerosene tin	..
	After cooling overnight	Kerosene tin	1430·0
3	First boiling	Iron drum	162·6
	Second boiling	Glass flask	101·0
	Growth of air-borne micro-organisms, 7 days at room temperature	..	9·9
4	First boiling	Iron drum	15·5
	Second boiling	Iron drum	23
	Third boiling	Kerosene tin	1070
	After cooling overnight	Kerosene tin	1245

The nitrite content of the soup was estimated after each boiling (Table 4). When the content had reached a level considered likely to be toxic, pigs which had been fasted overnight were dosed by stomach tube. The amount of soup administered was determined by its nitrite content and the body weight of the pig. It was intended to dose at the rate of 0·09 gm. per kgm., but in both trials where death resulted the nitrite content of the soups increased during the interval between the last estimation and drenching so that the doses given exceeded 0·09 gm. per kgm. (Table 5). The usual morning feed was omitted prior to drenching.

Blood haemoglobin estimations were made before and at intervals after dosing. Pigs which died were autopsied immediately after death.

Trial 1.

The water used in this trial had been collected at farm A six months previously. It contained at the commencement of the trial 2·06 p.p.m. sodium nitrite and 2783 p.p.m. sodium nitrate.

The soup was boiled in an iron drum, but the nitrite content did not rise to a level considered toxic for pigs. After three boilings the volume was considerably reduced. The soup was then transferred to a kerosene tin and again boiled. This fourth boiling increased the nitrite content to 720 p.p.m. Three litres of this soup were given to a pig (no. 492) weighing 37 kgm. The dose rate was 0·058 gm. sodium nitrite per kgm., but no adverse effects were noted.

Table 5.

Effect of Experimentally Prepared Soups (Table 4) on Pigs.

Trial.	Pig No.	Weight of Pig kgm.	Soup.		Dose Rate of $NaNO_2$ gm./kgm.	Haemoglobin (gm./100 ml.)		Result.
			Nitrite Content p.p.m.	Vol. Dosed ml.		Pre-treatment.	Just before Death.	
1	492	37	720	3000	0·058	..	..	No adverse effects
2	493	46	1430	4000	0·124	12·1	1·5*	Death in 51 minutes
2	496	38	1430	3200	0·120	10·7†	2·6	Death in 40 minutes
4	495	82·1	1245	6900	0·105	17·8	5·3	Death in 63 minutes
4	492	76·2	1245	3500	0·059	13·5	10·3‡	Non-fatal methaemoglobinaemia

* Sample taken just prior to death was showing a tendency to clot, so result is not accurate.

† The pre-treatment sample of approximately 5 ml. of blood was added to 0·5 ml. of aqueous sodium citrate, so the figure given is about 10% low. Dried sodium citrate was used for all other blood samples.

‡ Sample taken 2 hours after dosing.

Trial 2.

The water used in this trial (and in trials 3 and 4) was also from farm A and contained 8·4 p.p.m. sodium nitrite and 2331 p.p.m. sodium nitrate. Soup was prepared as in trial 1 and boiled for four hours in the iron drum. The first boiling increased the nitrite content to 258·8 p.p.m., but further boiling decreased the concentration, so that after the third boiling it was down to 156 p.p.m. The soup remaining in the drum was stored in glass jars for seven days, during which time there was a profuse bacterial growth. The soup was then transferred to a kerosene tin and boiled for the fourth time for four hours. The nitrite content rose to 1060 p.p.m. The soup was boiled a fifth time and then two pigs were each dosed with a quantity estimated to contain 0·09 gm. sodium nitrite per kgm. Subsequent analyses showed that the last boiling and cooling had increased the concentration to 1430 p.p.m. sodium nitrite. The pigs therefore

received a dose of 0·12 gm. per kgm. Both pigs developed severe methaemoglobinaemia. Death occurred 40 minutes (pig. no. 496) and 51 minutes (pig no. 493) after dosing.

Post-mortem examinations done immediately after death showed similar lesions in both pigs. The subcutaneous vessels were engorged with chocolate-coloured blood. The heart was in diastole but showed no macroscopic lesions. The lungs were pale and contracted, with a few subpleural petechiae. The stomach of one pig showed a marked catarrhal inflammation. The glandular mucosa was congested and seemed to strip rather readily. Inflammation of the duodenum was most marked and extended for several feet. The liver and kidneys were engorged with coffee-coloured blood. Samples of liver, spleen, kidney, stomach and intestinal contents were collected for chemical analysis (Table 6).

Table 6.

PIGS DOSED WITH EXPERIMENTAL COOKED OFFALS: SODIUM NITRITE CONTENT OF ORGANS FROM FATAL CASES.

—	Pig No.	Volume of Soup and Nitrite Content.	Weight of Pig kgm.	Dose Rate gm./kgm.	Specimen.	$NaNO_2$ p.p.m.
Trial 2	493	4000 ml. containing 1430 p.p.m. $NaNO_2$	46	0·124	Stomach content ..	7·6
..	..	..	..	..	Intestinal content ..	6·6
..	..	..	..	..	Liver	less than 1
..	..	..	..	..	Kidney	1·75
..	..	..	..	..	Spleen	1·6
Trial 2	496	3200 ml. containing 1430 p.p.m. $NaNO_2$	38	0·120	Stomach content ..	101
..	..	..	..	..	Intestinal content ..	5·7
..	..	..	..	..	Liver	less than 1
..	..	..	..	..	Kidney	2·75
..	..	..	..	..	Spleen	3·5
Trial 4	495	6900 ml. containing 1245 p.p.m. $NaNO_2$	82·1	0·105	Stomach content ..	478
..	..	..	..	..	Small intestinal content	514·5
..	..	..	..	..	Large intestinal content	less than 1
..	..	..	..	..	Liver	less than 1
..	..	..	..	..	Kidney	less than 1
..	..	..	..	..	Spleen	less than 1

Trial 3.

As trials 1 and 2 indicated that repeated boilings in the iron drum did not raise the nitrite content to a toxic level, it was thought that perhaps bacteria may have been responsible for the reduction of nitrate to nitrite, so the following experiment was undertaken.

A sample (about 2 litres) was taken from a batch of soup which had been boiled once for four hours in the iron drum. The nitrite content was 162·6 p.p.m. The sample was boiled for one hour in a flask and then exposed to contamination by air-borne micro-organisms for seven days. At this time the nitrite content was 9·9 p.p.m., compared with 101·0 p.p.m. immediately after boiling.

This experiment indicates that the increase in nitrite was not due to micro-organisms.

Trial 4.

Two boilings in the iron drum reduced the volume of soup from 11 gallons to $2\frac{3}{4}$ gallons. The nitrite content increased from 9 p.p.m. in the original water to 20 p.p.m.

The soup was then transferred to a kerosene tin and boiled for the third time. The nitrite content rose to 1070 p.p.m. After the soup had stood overnight in the tin, the nitrite content increased further to 1245 p.p.m.

This soup administered to pig no. 495 at the rate of 0·105 gm. per kgm. produced methaemoglobinaemia and death in 63 minutes. Observations on this animal were:—

Pig. No. 495. Weight 181 lb. (82·1 kgm.).

10.0 ..	Dosed by stomach tube with 6900 ml. of soup containing 1245 p.p.m. sodium nitrite.
10.5 ..	Urinated.
10.28 ..	Urinated.
10.29 ..	Paddling gait, respiratory rate 68 per minute.
10.35 ..	Respiratory rate 80 per minute.
10.37 ..	Animal lay down.
10.39 ..	Animal rose and defaecated.
10.40 ..	Restless; skin blanched.
10.47 ..	Vomited twice; quantity (estimated) 300-400 ml.
10.49 ..	Vomited about 200 ml.
10.50 ..	Marked ataxia.
10.51 ..	Went down and struggled.
10.53 ..	Buccal mucosa very cyanotic; marked respiratory distress.
10.55 ..	Animal lying on its side paddling; dyspnoeic.
11.03 ..	Death.

A post-mortem examination done within 30 minutes of death presented lesions identical with those described in trial 2. Liver, kidneys, spleen and contents of the alimentary tract were analysed for nitrites; the results are shown in Table 6. The remainder of this batch of soup (3,500 ml.) was administered to pig no. 492. The animal weighed 76·2 kgm. so the dose rate was 0·059 gm. sodium nitrite per kgm. Non-fatal symptoms of methaemoglobinaemia were exhibited.

The Reduction of Nitrate to Nitrite in Well Water.

The original well water from farm A contained approximately 10 p.p.m. sodium nitrite and 2800 p.p.m. sodium nitrate. It was thought at first that boiling with offal was sufficient to reduce the nitrate, but this was not substantiated by the experiments described above. Certain bacteria are capable of reducing nitrate to nitrite. It was considered that the increase in nitrite concentration in trial 2 may have been brought about in this manner, but this was not confirmed in trial 3.

Boiling in the iron drum resulted in an initial increase in nitrite followed by a decrease (trial 2). Concentration by boiling in this vessel did not increase the nitrite content. However, when the mixture was transferred to a kerosene tin and boiled there was, on each occasion (i.e., in trials 2 and 4), a marked increase in nitrite. It was felt that the tin coating of the kerosene tin may have been responsible for the conversion of nitrate to nitrite either by acting as a catalyst or by preventing the complete reduction of nitrate to ammonia.

DISCUSSION.

The evidence presented indicates that the field outbreaks were due to nitrite poisoning resulting from feeding offal cooked in water with a high nitrate content.

The mechanism of the reduction of nitrate to nitrite is still obscure. Suckling (1944) stated:—"Many waters containing nitrates, if allowed to stand in contact with iron, zinc or lead in pipes or cisterns, act upon the metal, the nitrates being in part reduced to nitrites and ammonia." This might explain the increase in nitrite in the water samples kept in the glass jars with metal screw caps and also in the water stored in the iron tank at farm A.

The experiments reported here in which offal was boiled in an iron drum and in a kerosene tin do not duplicate the conditions at farm A, where the boiling was done in a cast iron vat. Also, in the field excess soup was retained and boiled with the next batch of offal. Further chemical experiments are being done on the factors concerned in the production of nitrite from these waters.

The excess nitrate in the soup did not appear sufficient to be toxic, because in trial 1 pig no. 492 received 0·058 gm. per kgm. sodium nitrite plus the unreduced nitrate and suffered no ill effects.

From their work on nitrite poisoning in pigs fed on cooked mangels, McIntosh *et al.* (1943) concluded:—"Mangels cooked at temperatures below boiling point, or for too short a time at boiling point, were shown to be dangerous to pigs, owing to the amount of nitrite formed during cooling. . . . Production of nitrite on cooling may be avoided by boiling mangels for at least two hours, at or near boiling point." McIntosh (1950) points out that in their experiments

no nitrite was present at the completion of the cooking. All the nitrite was produced during cooling and its presence or absence depended solely on the temperature during cooking. In cooked offal, on the other hand, toxic levels of nitrite are not avoided by cooking at 100 deg. C., because a vat at farm A which had been boiling for several hours and was still boiling when sampled, contained 1127 p.p.m. sodium nitrite (Table 1).

In Queensland, four natural well waters, besides those from farms A and B described above, have been encountered with nitrate contents ranging from 270 to 4000 p.p.m. There is a record also of a sub-artesian water analysed in the Department's Chemical Laboratory in 1930 containing the equivalent of 2380 p.p.m. sodium nitrate. This water was submitted as the suspected cause of deaths in sheep, but the particulars of the outbreak could not be found. The observations reported above indicate the danger of using such waters to prepare cooked offal for feeding to pigs. Such waters may be dangerous also to human beings, particularly infants. Faucett and Miller (1946) record three cases of methaemoglobinaemia in infants fed milk mixtures diluted with well waters high in nitrate. The water used by two patients contained 70 mgm. nitrate nitrogen per litre (i.e., 425 p.p.m. sodium nitrate) and a trace of nitrite nitrogen per litre. In the other case the well water contained 300 mgm. nitrate nitrogen per litre (i.e., 1821 p.p.m. sodium nitrate) and a trace of nitrite nitrogen per litre. Ferrant (1946) reported two cases of methaemoglobinaemia in newborn infants fed a powdered milk formula made up with boiled well water. In the first case the water contained 497 p.p.m. nitrate (i.e., 681 p.p.m. sodium nitrate) and 0·114 p.p.m. nitrite (i.e., 0·171 p.p.m. sodium nitrite), and in the second case 180 p.p.m. nitrate (i.e., 247 p.p.m. sodium nitrate) and a trace of nitrite.

Gwatkin and Plummer (1946) showed that pigs dosed with 10 per cent. solution of potassium nitrite after 24 hours fasting died of methaemoglobinaemia, whereas pigs given a similar dose rate without previous fasting suffered only slight ill effects. The presence of food in the stomach probably prevents fatal anoxaemia from sudden conversion of haemoglobin to methaemoglobin by delaying absorption of nitrite. It seems, therefore, that in the field mortality from nitrite poisoning may be greatly influenced by the amount of ingesta in the stomach when the nitrite-containing feed is given.

Nitrite poisoning can be diagnosed by the distinct brown colour imparted to the blood by methaemoglobin. The brown colour is readily detected in sick or freshly dead animals but it may not be detected if the autopsy is done several hours after death, because the methaemoglobin is converted by bacteria back to haemoglobin (Williams and Hines, 1940).

The nitrite content of specimens from pigs which died of experimental nitrite poisoning (Tables 3 and 6) indicates that the stomach content is the most suitable specimen for diagnosis, though there is a wide variation in the amount of nitrite recovered. The stomach contents of three pigs which died after dosing with experimental cooked offals contained 7·6, 101 and 478 p.p.m. sodium nitrite (Table 6). The variation is presumably due to the action on the

nitrite of enzymes and bacteria. Thus the presence of only a small amount of nitrite in the stomach or other organs does not necessarily exclude a diagnosis of nitrite poisoning.

Symptoms and lesions of fatal nitrite poisoning were produced in three pigs dosed with these soups in amounts corresponding to 0·105, 0·120 and 0·124 gm. sodium nitrite per kgm. body weight.

ACKNOWLEDGMENTS.

Grateful acknowledgment is made to Messrs. S. M. Seamer and P. Round (Inspectors of Stock at Beaudesert and Pittsworth, respectively) for providing the original specimens and information pertaining to affected farms and for assistance in subsequent investigations; to Mr. W. McCray (Analyst, Chemical Laboratory) for most of the later nitrite determinations; and to Mr. J. M. Harvey, M.Sc. (Biochemist, Chemical Laboratory) for haemoglobin determinations.

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DESCRIPTION OF A LATERITE PROFILE NEAR GAYNDAH, QUEENSLAND.

By L. J. H. TEAKLE, B.Sc.Agric., Ph.D., A.A.C.I., Professor of Agriculture, University of Queensland.

SUMMARY.

Current views on the structure and origin of laterite are summarized briefly, and a laterite profile with a depth of over 200 feet, indicating a long period of laterisation, is described.

INTRODUCTION.

The purpose of this communication is to report a spectacular occurrence of laterite near Gayndah, in south-eastern Queensland, and to give a brief description of the components of the profile. No chemical analyses of the material in the component horizons are available to add to the descriptions, as no facilities were available for chemical work; but it is considered that, for the purpose of this paper, the field observations are of sufficient importance to warrant publication without supporting chemical data.

WHAT IS LATERITE?

The term laterite was used first in 1807 by Buchanan* and was the name given by him to a type of red soil which is of frequent occurrence in southern India. These red soils are characterised by layers of ferruginous concretions and segregations which present a soft, cheesy consistency when freshly exposed and harden on exposure. On this account laterite was found to be very convenient for making bricks; hence the derivation of the name from the Latin *later*—brick.

The term was adopted by pedologists and applied to a wide variety of soils and materials in tropical and subtropical parts of the world. The result was utter confusion, which is only now being resolved. Much of this confusion arose from attempts to regard laterite simply as a material with certain chemical properties. One definition defined laterite as a material in which the molecular ratio of silica to alumina in the clay is less than 1·33. This would include many materials not even remotely resembling the components of Buchanan's red soil. It would exclude Buchanan's original laterite.

The idea of laterite as a soil in which the silica: alumina or silica: sesquioxide ratio of the clay fraction falls within certain narrow limits has now been abandoned by most workers. This conception of laterite once received strong support from pedologists in the United States, but the present viewpoint

* See Russell, E. J. 1932. Soil Conditions and Plant Growth. 6th ed., p. 281.

in that country is now clearly stated by Kellogg and Davol (1949), who use the term for "the sesquioxide-rich, highly weathered clayey materials that change irreversibly to concretions, hardpans, or crusts, when dehydrated, and for the hardened relicts of such material, more or less mixed with entrapped quartz and other materials. Many of the clays and hardpans have prominent reticulate mottling with some combination of yellow, red, brown, white, grey, and black." This is the laterite of Buchanan, Campbell (1917), Mohr (1930), Pendleton (Pendleton, 1941; Pendleton and Sharasuvana, 1942), Prescott (1931), Humbert (1948) and many other authorities.

Laterite as defined by Buchanan is particularly common in tropical countries—India, Siam, Java, Africa, South America and New Guinea, to mention but a few. It has been recognised, also, in the United States and in Mediterranean countries, and is of widespread occurrence in Australia.

Laterite has formed on many types of rocks. In fact, it appears to be the product of certain climatic, drainage and topographic conditions, and the rock type merely affects the character of the laterite. Basic rocks appear to yield laterite and associated upper soil of dominantly red colours; on acidic rocks the laterite is commonly brown to yellow brown and the soil profile above greyish and yellowish in colour.

While it is not intended to discuss theories proposed to explain the formation of laterites, attention is directed to that offered by Pendleton (1941). Pendleton considers laterites to be ground-water formations which develop on level or gently-sloping relief. The ground-water level is presumed to fluctuate seasonally with variations in the rainfall, giving two zones:—

(1) A zone of permanent saturation and persistent reducing conditions; and

(2) A zone above this of intermittent saturation where there would be an alternation of reducing and oxidizing conditions.

Iron dissolved under reducing conditions would deposit to form a characteristic pattern in the zone of intermittent saturation.

During the process of laterite formation there would be loss by drainage of potassium, calcium, magnesium and related cations, and of silica.

THE LATERITE PROFILE.

Observations in Australia suggest that "laterite" is normally part of a profile, or group of genetically related horizons. These observations are supported by many writers on the subject, but there is a divergence of opinion on the relationship between the laterite and the associated soil profile.

The *complete* laterite profile as observed in Australia appears to consist of six distinct layers. Commencing at the surface these are:—

(1) An unconsolidated and uncemented surface showing features of the upper part of a soil profile.

(2) A zone of enrichment with sesquioxides in pisolitic form embedded in the soil matrix.

(3) A zone of enrichment with sesquioxides in which a cellular or vesicular structure has developed. The cavities contain soil material or kaolinitic clay, which may be removed on exposure and weathering, leaving a honeycomb of sesquioxide material.

(4) A mottled zone of kaolinitic material irregularly impregnated with or invaded by sesquioxidic material, brown or reddish in colour due to its content of ferric oxide.

This zone merges into the layer above it and also into the pallid zone below it.

(5) A layer of white or whitish kaolinitic material which has been termed the pallid zone by Whitehouse (1940). This layer may be distinctly pinkish at times, due to impregnation with small amounts of red iron oxide.

(6) A zone of enrichment with silica constituting the base of the profile. This may occur as a quartzite known in Queensland and New South Wales as "billy." It may be quite soft or extremely hard.

Below the profile is the weathering parent rock, which may be regarded as the seventh layer. (An interesting example of weathered rock below laterite is described by Humbert (1948).)

There are many examples of incomplete profiles. The horizon of silica deposition may be absent; the pallid zone may be imperfectly developed, or absent; some of the upper layers may be lost by truncation, etc.

LATERITE AN ANCIENT FORMATION.

Much of the laterite observed in many parts of the world appears to be an ancient formation.

Of course, there is no lack of evidence that laterite is forming in certain areas at the present time. Considering the range of present-day climates it would be extraordinary if this were not so. Dr. C. E. Kellogg* considers that laterite is in the process of formation in certain soils of Belgian Congo; G. A. Stewart* claims that laterite is forming now in the Northern Territory of Australia. Humbert's (1948) observations in New Guinea may be interpreted to indicate that laterites are now forming in "areas with climates between humid and arid regions" and "occur almost exclusively on level to gently sloping relief." The "laterite is generally formed within the zone of intermittent saturation."

But there is overwhelming evidence that the laterite of many formations is the product of a by-gone age, that it commenced to form a long time ago,

* Private communications.

and that dissection and truncation are now effecting denudation. Prescott (1931) referred to such soils containing laterite in Australia as "fossil" soils. While this term emphasises the concept of age and the absence of laterising conditions to-day at these sites, it is not particularly appropriate. The sequence of changes in climatic conditions since laterite commenced to form seems to have effected little or no fundamental change in the laterite, except by denudation. Laterite, composed as it is largely of sesquioxides and kaolinite, is not responsive to such changes and may be cited as an example of "pedogenic inertia" (Bryan and Teakle, 1949). It is suggested that the processes of laterisation have slowed down, perhaps even stopped, under the changed conditions, but there is little evidence of actual reversal in the direction of the main chemical processes. The laterite would be better regarded as "senescent" than as "fossil." The term "senescent" has been used by Stephens (1947) for certain South Australian soils.

Bryan (1946) restricts the term "fossil" to soils buried and preserved by an overlay of material such as sediments or lava. He suggests the term "inherited" for soils, such as laterite, which show evidence of the effects of an earlier period.

Much, if not most, of the laterite in Australia is ancient. There is geological evidence that it commenced to form in late Miocene or early Pliocene times—say 12 to 15 million years ago—when the climate must have been propitious and much of the land surface had been reduced to base level by planation. These conditions must have persisted for a very long time before uplift or eustatic movements rejuvenated drainage with consequent dissection and truncation.

THE GAYNDAH LATERITE.

The profile described hereunder as the Gayndah laterite occurs on the Binjour Plateau, which lies in the Gayndah district about 250 miles north-west of Brisbane. The natural vegetation of the district is mainly of open and closed forest types. The vegetation carried on the profile to be described is an open eucalyptus woodland; the chief trees are spotted gum (*Eucalyptus maculata*), narrow-leaf ironbark (*E. crebra* or *E. paniculata*), and messmate (*E. obliqua*), and there is a ground cover of native grasses.

The mean annual rainfall of the district is about 30 inches, with a marked summer incidence.

District soil types include recent river alluvials, podzolics, black clays, "red loams," laterites and skeletal types.

Binjour Plateau is capped by Tertiary basalt which overlies Palaeozoic rocks. On the eastern side, the plateau presents an escarpment which rises about 700 feet above the bed of Reid's creek. Characteristic of this escarpment are sheer cliff faces up to 45 feet high. The escarpment appears to form a rim to the plateau, as the centre is much lower—some 300 to 400 feet—apparently as a result of internal erosion.

Recent examination of the laterite exposures both at the natural cliffs and in road cuttings revealed details which are represented in Figures 1 and 2. The cliff face was measured with a surveyor's chain and other heights were estimated from altimeter readings. In constructing the figures, it has been assumed that the contact between the basalt and the laterite is horizontal, as also are the profile horizons of the laterite. It is recognised that neither of these assumptions will be strictly correct, but it is unlikely that deviations

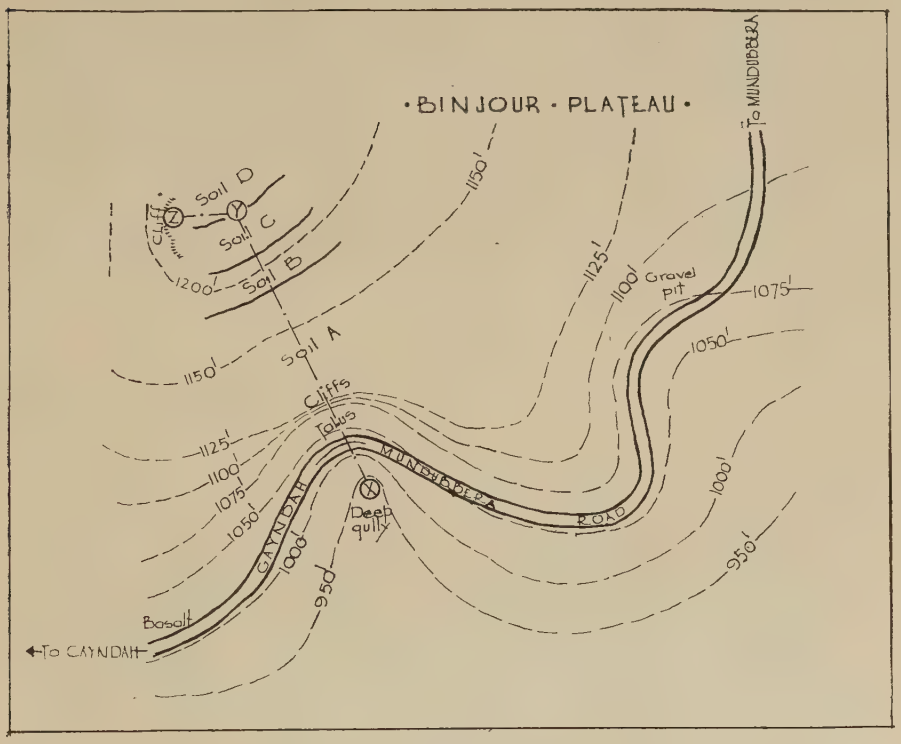

Figure 1.

Diagrammatic representation of the contours of the escarpment of Binjour Plateau with the road ascending from Reid's Creek valley to the top of the plateau. The line XYZ shows the location of the traverse from which the section represented in Figure 2 was constructed.

would alter the order of magnitude of the figures deduced. The costly expedient of sinking shafts was out of the question, so the nature of some of the layers was deduced from the stones and gravel strewn on the surface along the traverse of the plateau examined. The contour lines and location of the road in Fig. 1 are largely diagrammatic. Elevations were measured by the altimeter along the road and along the traverse XY. According to the speedometer readings, the gravel pit was 0·4 miles from the traverse XY and the first exposure of basalt 0·2 miles. The point Y, at the highest point of the traverse, was 23 chains from the road.

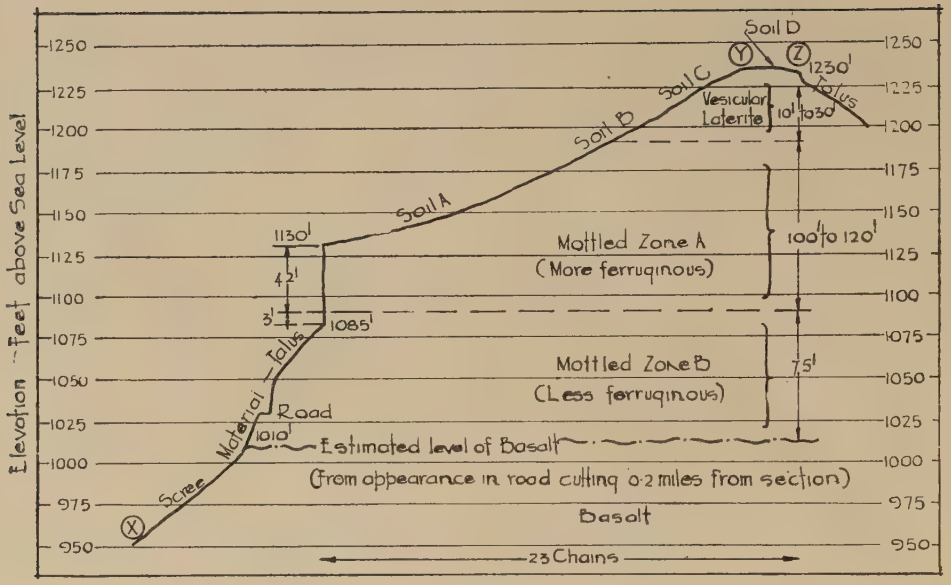

Figure 2.

Diagrammatic representation of the section through the traverse XYZ of Figure 1. The section reveals a mottled zone of about 200 feet in thickness which appears to be capped by hardened vesicular laterite. Above the cliffs the soil is of the "red loam" type. Four subdivisions of this soil are recognised on the basis of the nature of the gravel and stones observed on the surface. The gravel and stones are indicative of the underlying lateritic material.

Figure 3.

General view of the escarpment of Binjour Plateau. The laterite cliff of the extreme left is about 45 feet high. The vertical graining of this laterite is shown in Figure 4.

Figure 4.

Vertical graining of the mottled zone of the laterite at the site of Figure 3. Elevation about 1,090 feet. This is considered to represent the junction of Zones A and B in the mottled layer.

Figure 5.

Horizontal graining of the mottled zone of the laterite on the escarpment of Binjour Plateau 0.4 miles from the site of Figure 3. Elevation about 1,080 feet.

It appears that here is a laterite profile of approximately 200 feet. Assuming that the basalt occurs at the 1010 feet level, there is about 120 feet of mottled zone to the top of the cliff. From a study of the cliff face it seems that the lower 75 feet of this zone shows a predominance of whitish kaolin. This is designated mottled zone B in Fig. 2. The upper part, designated mottled Zone A, is over 40 feet to the top of the cliff and is more highly ferruginous. No evidence of a true pallid zone or of a silicified layer (billy) was observed. Fig. 3 gives a general view of the escarpment with the 45 feet laterite (mottled zone) cliffs at the site measured. The obvious vertical graining of this laterite at the 1090 feet level is shown in Fig. 4. Curiously, at the gravel pit 0·4 miles along the road up the escarpment and where the elevation is about 1080 feet, the laterite shows a horizontal graining (see Fig. 5). No evidence of fault or landslide was observed.

Above the cliff top the plateau rises at least 100 feet to Y on the traverse at a slope of about four feet per chain. There are no rock exposures, and, in the absence of pits or borings, the nature of the underlying material was judged from the gravel and stones strewn on the surface. Four subdivisions were recognised:—

(A) A "red loam" soil with stones consisting of fragmental material of mottled zone A (the more ferruginous type). This persists for a rise of about 50 feet above the top of the cliff.

(B) For the next 30 feet vertical the soil seems similar but the stones are of the hardened, vesicular laterite type.

(C) Above this is a zone of about 20 feet in thickness vertically where the surface is strewn with stones and gravel derived from hardened, vesicular laterite.

(D) On the higher levels the soil is of the red loam type, with only a little lateritic gravel.

These observations lead to the conclusion that the mottled zone (type A) extends well up the slope, probably to about the 1200 feet level (Fig. 2). Above this there is layer of hardened, vesicular laterite between 10 and 30 feet in thickness. It is estimated that the mottled zone, including both A and B, is approximately 200 feet thick.

It is concluded that this laterite profile exceeds 200 feet in vertical section and that the mottled zone alone approximates 200 feet in thickness. It is considered that laterisation commenced in Pliocene times and must have continued over a very long period to account for such a thickness of laterite.

ACKNOWLEDGMENT.

Thanks are expressed to Professor W. H. Bryan for helpful criticisms in the preparation of this paper.

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THE COTTON JASSID PROBLEM IN QUEENSLAND.

By A. W. S. MAY, M.Agr Sc., Entomologist, Science Branch, Division of Plant Industry.

SUMMARY.

The cotton jassid (Empoasca maculata) *affecting American Upland varieties of cotton grown in Queensland is shown to differ from the more important species affecting cotton elsewhere in that it restricts its activity to the terminal growth of the plant.*

Oviposition and feeding injuries are intensified with increase in jassid population on the plant; severe damage suppresses plant growth and depresses yields of lint.

Early spring rains influence jassid development during the early summer, but the most severe injury is associated with the late summer rainy period, when the plants are growing rapidly.

Soil condition, cultural treatment, time of planting, and variety of cotton are shown to influence plant susceptibility to jassid injury.

The breeding of jassid-resistant varieties is stated to be the only control measure which is likely to be practicable.

INTRODUCTION.

Jassids have attained importance as pests of cotton in several countries where this crop is grown commercially. Though the species concerned and their respective habits vary considerably in the several regions where these pests are recorded, the damage produced and the ultimate effect on plant growth and crop formation are somewhat similar.

In contrast with the position overseas, it is only in recent years that the jassid problem has become a widespread major factor in cotton production in Queensland. Though damage may fluctuate from year to year, the increasing importance of this pest some years ago threatened to limit production in areas suitable for the development and expansion of cotton growing. Accordingly, a study of the problem was initiated in 1941. The specific identification of the jassids concerned preceded investigations into their relative importance as pests, and once the identity of the cotton jassid was established an observational study of the bionomics and types of damage produced was undertaken. This work was followed by a more detailed study of plant reaction to attack and the part played by plant hairiness, which will be reported in a later paper.

SPECIES OF COTTON JASSIDS.

The earliest known records of jassids attacking cotton come from India, where according to Verma and Afzal (1940) introduced American and Egyptian varieties were damaged in Bihar province in 1906. These workers traced the incidence of jassid pests in the Punjab in 1913-14, Cawnpore in 1916, North Bihar in 1919, Madras in 1935, and Sind in 1936. Prior to the introduction of American Upland cotton into the Punjab on a commercial scale, jassids were of little importance, as the Asiatic cotton (*Gossypium arboreum* var. *neglectum* H. et G.), grown previously, is practically immune to the pest (Afzal, 1941). Further records from the Indian region show that this pest is now widespread, while Gwynn (1938) recorded jassids as a pest of cotton in Ceylon.

In India, numerous species have been recorded from cotton, though the taxonomic validity of some of the species is uncertain (Husain, 1938). According to Husain, by far the most important species (*Empoasca devastans* Dist.) injures crops in the Punjab, Sind and Madras, while two other species—*E. gossypii* De Long and *E. notata* Mel—have also been recorded from those areas. Cherian and Kylasam (1938) stated that two species—*E. devastans* Dist. and *E. formosana* Paoli—are found on Cambodia, Uppana and Karunganni cottons in Madras Province, but the former is by far the more abundant. Recently three new species—*E. minor* Pruthi, *E. kerri* var. *motti* Pruthi, and *E. punjabensis* Pruthi—were recorded from cotton in the Punjab, but they are of little economic importance (Afzal and Abbas, 1945).

Verma and Afzal (1940), quoting from earlier records, cited *Empoasca flavescens* F. as a pest of cotton in the Philippines. The species implicated in Fiji was described by Anson (1928) as a small yellow jassid but has not been identified.

In Africa the dominant species on cotton (*Empoasca facialis* Jac.) has been recorded from the French Sudan, Nigeria, Southern Rhodesia, Uganda, Kenya, Anglo-Egyptian Sudan, Swaziland, Transvaal, and other cotton-growing regions. Husain (1938), in a survey of species attacking cotton, cited *E. facialis* as the dominant species in Africa. He stated also that *Erythroneura lubiae* China is found on cotton in the Anglo-Egyptian Sudan and Italian Somaliland, and that other species (including *E. distinguenda* Paoli and *E. benedottoi* Paoli) have also been recorded from cotton, though their economic status is uncertain.

In Queensland, Ballard (1925) recorded the presence of jassids in large numbers in crops at Mount Larcom and in the vicinity of Emerald, and stated that a few individuals may be encountered in crops elsewhere. During the 1935-36 season the pest caused serious damage throughout the Callide and Burnett Valleys. Sloan (1938) found the pest widespread throughout the cotton districts of Central Queensland. At present, this pest occurs in all the cotton-producing areas of the State.

The earliest records of jassids as pests of cotton in Queensland do not designate the species concerned, but merely indicate that the pests belonged to the genus *Empoasca*. For a considerable time their identity remained obscure and a great deal of the damage now known to be caused by the cotton jassid was wrongly attributed to the tomato jassid (*E. terra-reginae* Paoli). This latter species is frequently associated with cotton, particularly during the early life of a crop and was identified as a pest of cotton at Biloela (Sloan, 1938). Though Sloan stated that damage to cotton in the Upper Burnett, Callide and Dawson Valleys may have been due to jassids of the genus *Empoasca*, he discounted the possibility that *E. terra-reginae* was the only jassid concerned and concluded that "other unidentified species may also be implicated."

Following a study of jassid material collected from several cotton-growing districts in 1941, it was obvious that another and more important species was associated with the typical damage attributable to jassid attack. This species has been described (Evans, 1941) as *Empoasca maculata*. Later, cotton jassid material in the collection of the Queensland Department of Agriculture and Stock, that had been collected from cotton severely affected by jassids at Yamala, near Emerald, in 1924, was identified as *E. maculata*.

Apart from *E. maculata* and *E. terra-reginae*, two other species—*E. alfalfae* Evans and *Thamnotettix argentata* Evans—may also be found on cotton, but they are of no economic importance.

A comparison of the habits and damage of the Indian and African species, *E. devastans* and *E. facialis*, with *E. maculata* suggests that the jassids attacking cotton overseas have somewhat different habits from the principal pest species here. Unlike *E. maculata*, *E. devastans* is not confined to the region of terminal growth, while *E. facialis* may be found on all parts of the plant. In both Africa and India the general picture of plant injury is much the same as found in Queensland; workers in both these countries (Parnell, 1925; Moerdyk, 1927; Husain, 1938) recording leaf curling accompanied by discolouration and final necrosis of the damaged tissues. The information given by Parnell (1925) shows that the mode of jassid injury and the factors governing such injury are far different in Africa from those experienced in Queensland, though the ultimate effect on cropping may be the same. The African species may oviposit on any part of the plant, causing injury symptoms to develop rapidly, and the majority of leaves on each plant may support a nymphal population. Leaf curling and discolouration are also features of the attack, while total defoliation of plants is not uncommon. Another characteristic which differentiates *E. facialis* from *E. maculata* is the ability of the African species to produce severe damage during years which do not favour normal plant development.

BIONOMICS OF EMPOASCA MACULATA.

Description of the Adult.

The adult of *E. maculata* (see Fig. 1) is a bright-yellow leaf hopper. The distinguishing external characteristics of the species are given by Evans (1941) as follows:—

> "*Length* 3 mm. General colouration bright yellow. *Head,* ventral surface white, but for the fronto-clypeus antero-laterally, which is green; eyes black. Crown yellow, with or without white markings; ocelli marginal, large. *Pronotum* yellow with irregular white markings, usually four in number, lying against the

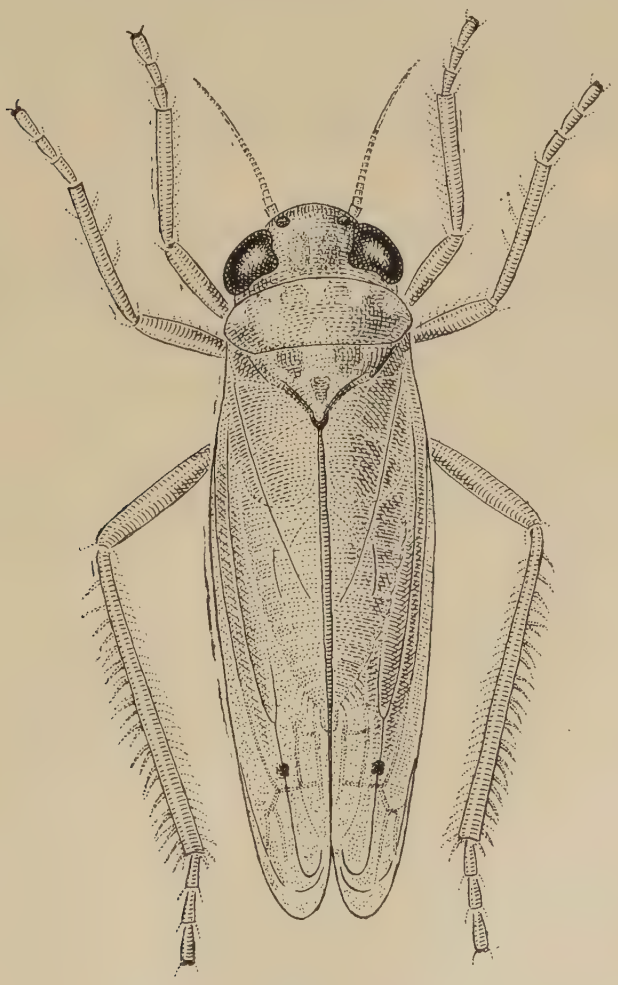

Figure 1.

Adult of *Empoasca maculata* (x30).

[*Drawing by William Manley*

anterior border. *Scutellum* yellow with white markings. *Tegmen* yellow, hyaline with a distinct brown spot in the distal portion of the cell that lies between the claval suture and Cu 1. . . . ."

"*Note.—E. maculata* resembles *E. terra-reginae* Paoli in the shape and colour pattern of the head and pronotum. It differs in colour, being yellow and not green, and may be readily identified by the presence of the brown spot in the tegmen."

Development and Behaviour.

The field survey of the cotton jassid problem did not afford an opportunity for a detailed study of the life history of *E. maculata*. It seems, however, that given ideal conditions for breeding and survival, the population increase is extremely rapid and the number of eggs laid by each female relatively high. For the related species, *E. terra-reginae*, the life cycle is completed in from 25 to 30 days in June at Bowen (Atherton, 1933).

Oviposition.

Egg-laying is only associated with leaves of a growing terminal and leaves that have not fully expanded. Thus, other factors being equal, population increase will be correlated with the rate at which new leaves are formed by the plant. Whenever conditions favour rapid and sustained vegetative growth, jassid development can proceed apace on susceptible varieties. Conversely, should plant growth be retarded, increase in jassid population is slowed also.

The eggs are placed principally within the tissues on the undersurface of the larger leaf veins, but may be found also in the petioles and the terminal portions of the stems. The eggs, sickle shaped and faint greenish in colour, are inserted singly with their long axis parallel to the direction of the vein. The number of eggs laid in any part of the vein varies with its diameter, the greater number being laid in the basal half.

Oviposition punctures may be evident on the young leaves soon after they open, and the number of eggs per leaf on a growing terminal increases on successive leaves to attain a maximum on the third or fourth leaf below the growing point.

Nymphs.

Hatching invariably occurs in the early morning and nymphs arising from those eggs deposited in the petioles and stems migrate to the nearest leaves soon after hatching. The newly-emerged nymphs are almost colourless and relatively inactive, sheltering in leaf folds or alongside the larger veins. With feeding and subsequent growth, activity increases and the individuals assume a faint yellowish-green colour. The more mature nymphs and the pre-adult stage are coloured a uniform rich yellow.

The nymphs are particularly active when disturbed, moving with a characteristic sideways and then forward motion in search of shelter. They are sensitive to direct sunlight, and soon seek shelter on the undersurface when leaves are turned for examination. The early instar nymphs are particularly difficult to dislodge from the foliage by shaking, while the almost mature nymphs, as well as the pre-adult stage, hop and move about the plant quite freely when disturbed. This greater degree of mobility also enables them to spread from the leaves where the eggs were deposited.

Adult.

The adults are very active and readily move from plant to plant. When disturbed, they fly rapidly, seeking shelter on the undersurfaces of leaves of plants in the vicinity. When confined to glass tubes in midsummer, adults failed to survive longer than 24 hours without food, but when supplied regularly with fresh cotton leaves this period was increased to 12 days. However, the duration of adult life in the field may be even longer.

Feeding Habits.

Feeding is confined to veins on the undersurface of the leaf, and though the adult and more mature nymphs may ingest cell sap from the larger veins, most feeding is associated with the lesser veins. Chloroplasts taken up in the sap may give rise to a small green spot in the abdomen of the semi-transparent early stage nymphs. The insect remains stationary for a considerable period while feeding, piercing and re-piercing the veins with its proboscis.

Distribution on the Cotton Plant.

Newly-emerged nymphs usually complete their development on the leaves in which the eggs were deposited, and nymphal populations are rarely associated with the more newly formed leaves of a terminal unless plant growth has been arrested. Nymphal development is completed before many more new leaves are formed, and therefore the densest populations are between the 3rd and 6th leaves from the growing point. Below this region the nymphal population decreases sharply and consists of more mature individuals. In a severe infestation, as many as 30 nymphs may be found feeding under a single leaf, while a six-leaved terminal may carry a population of over 100. The marginal curling associated with such an infestation provides ideal shelter throughout the development of the nymphs.

The adults may be encountered on any part of the foliage but are more usually found in the vicinity of the growing point, where egg-laying activity is centred.

Though the leaves at the apex of the main stem invariably carry the greater proportion of the population associated with an infested plant, all growing points provide a medium for egg-laying and nymphal development. The growing points of the main stem and vegetative branches provide better

conditions for jassid breeding than those of the fruiting and extra-axillary branches. The diagrammatic sketch in Figure 2 is an example of the distribution of the population on an infested plant selected at random.

Alternate Hosts.

Early in each cotton season, *E. maculata* presumably spreads from its overwintering hosts and infests the new season's crop. Possible sources of infestation would be expected in those areas more subject to regular attack, and accordingly a host survey was undertaken to shed light on this aspect of the problem.

An examination of ratoon cotton has failed to reveal the presence of jassids during winter months. As the old stalks are invariably cut down or destroyed by stock prior to this period, there is no growth which could provide facilities for overwintering. However, as new foliage develops in the early spring, ratoon cotton may become infested and maintain the pest until the new season's crop is sown.

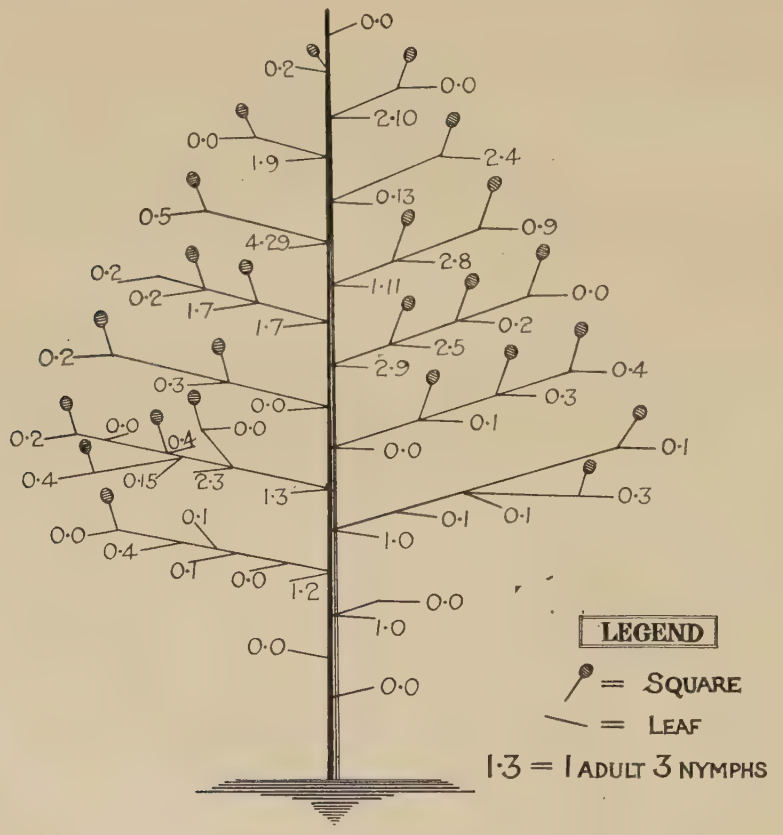

Figure 2.
Diagram Showing Distribution of Adults and Nymphs of *Empoasca maculata* on a Cotton Plant.

[*Drawing by William Manley.*

For a number of years the practice of ratooning cotton has been discouraged, and ratoon crops are now so rarely encountered that they could hardly give rise to widespread jassid infestation. Newly planted crops have become infested early in the season where no ratoon or standover cotton could be associated with this infestation.

Since ratoon and standover cotton plants do not normally serve as overwintering hosts, a thorough search was made of all plants which might support the insect. The comparative absence of jassids in certain years and their appearance in crops growing on newly cleared land, far removed from areas where cotton has been cultivated previously, suggests that other hosts are widespread. Though a large number of weeds and shrubs was examined, the number found to support the cotton jassid was surprisingly small. The significance of each host is discussed below.

Clerodendron tomentosum R. Br. (Verbenaceae) is found among regrowth monsoon forest throughout the Central and Upper Burnett. It is a very widely distributed tall shrub or small tree, the foliage and inflorescence of which may or may not exhibit a velvety pubescence.

In one locality near Gayndah, a number of these shrubs carried a heavy infestation of adult jassids towards the end of June, but the population decreased fairly rapidly as the winter progressed. No nymphal instars were recorded during this period. However, the adult infestation was noticed only in one year, and had originated from a heavily infested cotton crop nearby. In subsequent years, cotton was not grown in this locality and jassids failed to appear on these shrubs, while examination of specimens in other districts also failed to reveal any evidence of jassid infestation during the colder months. This is the only record of a plant supporting jassids during the winter months, but it is doubtful whether it can be classed as an overwintering host for the jassid.

Abutilon sp. (Malvaceae) is a tall growing herbaceous perennial, tomentose, large leaved, and commonly found in monsoon forests and on these forest lands after they have been cleared for cultivation. This plant is often encountered in suitable habitats throughout the Burnett Valley, and was occasionally found to support both adults and nymphs of *E. maculata* when growing in or very near fields of jassid-infested cotton. However, these migrants from the adjacent cotton invariably failed to overwinter on this plant and any infestation of *Abutilon* was of a secondary character.

Sida corrugata Linn. (Malvaceae) is a perennial procumbent weed found growing on forest soils of the Burnett. This weed also supports all stages of the cotton jassid as migrants from neighbouring infested cotton fields. Its occurrence in relatively low-lying areas subject to frost suggests its unsuitability as an overwintering host.

Amaranthus viridis Linn. (Amarantaceae) is a common weed which, when growing among infested cotton, can provide a source of food for adult jassids, but being a summer-growing annual it cannot be an overwintering host. Nymphal instars were never located on this plant.

Chenopodium carinatum R. Br. (Chenopodiaceae), like the previous weeds, was found to support the adult insect only when growing near infested cotton. Its annual habit would detract from its importance as a host, and though feeding does take place, rarely does the adult population attain any magnitude.

During this survey other jassids were encountered, and it was evident that the adults of these species have a much greater host distribution than the nymphs. Also, once their normal host has died or been destroyed, the adults migrate to and feed on other plants not necessarily related to the previous host. Thus it is probable that, after the completion of the cotton season, adult cotton jassids are able to survive on quite a number of plants other than those observed. Furthermore, in the spring months adult populations are seldom large and the pest rarely occurs in appreciable numbers before early January. This would suggest a low winter survival or conditions unsuited to the pest's development during the early summer months. A list of the jassids encountered and their host ranges is set out in the appendix.

Seasonal Population Trends.

The development of jassid populations in the spring is largely dependent on the availability of host plants and suitable seasonal conditions. Once infestation is apparent, the subsequent build-up depends almost entirely on the growth of the crop and the susceptibilities of the cotton varieties concerned.

Early spring rains may promote a relatively high jassid population during the early growth stages of a September-planted crop, but the subsequent population will be dependent on the seasonal conditions during the early summer months. The hot, dry periods of relatively short duration during the early summer and midsummer months periodically check plant growth and retard the rate of population increase. In these circumstances the pest rarely attains significance prior to early square formation. These periodical checks to plant growth in early summer may arrest breeding, but the adults will remain on the plant and resume oviposition in the new growth as the bush responds to more favourable conditions. Should summer conditions fail to produce rapid and continuous growth following good growing conditions in the spring, the rate of population increase will be slowed down and even a heavy infestation early in the life of the crop may eventually fade to unimportance.

In years when regular summer storms occur, adult survival between periods of growth ensures a steady and protracted population build-up until, with the advent of the late summer rains, rapid plant growth, particularly in late planted or late maturing varieties, presents ideal conditions for jassid development and peak populations ensue. The resultant injury to the plants and the relatively dry and cool conditions in the autumn are unfavourable to further jassid development, and populations wane at rates dependent on the severity of these separate influencing factors. Individuals may still persist on the plants until plant growth is finally arrested by the first frosts.

INJURY CAUSED BY E. MACULATA.

Leaf Symptoms and Damage.

Feeding is entirely on the undersurface of leaves, the nymphs, except a small proportion of older nymphs, confining their attention to the smaller veins nearer the leaf margins. The activity of only a very few nymphs per leaf may not greatly affect plant growth, but with larger populations the characteristic symptoms develop.

Loss of cell sap from the veins is followed by reduced turgidity in those regions adjacent to the affected areas, and partial wilting of leaves may result. However, this wilting is usually temporary, though necrosis of the affected tissues occurs on hot, dry days. A more permanent symptom is the downward curling of the leaf margins. At first this may be localised to areas of early feeding, but as the nymphs grow and spread to other parts of the leaves the curling is intensified until entire leaf margins are affected. Continued feeding may so intensify curling that the margins eventually contact the undersurface of the leaves. When viewed from above, those portions of the leaf lamina near feeding punctures gradually become yellowish green. Coupled with this intensified rolling is a general discolouration of the entire leaf, bronzed, yellowish-green and green areas combining to give the leaf a mottled appearance.

Nymphal damage is chiefly around the terminal growth. As these damaged leaves age, a general bronzing of the marginal areas takes place, particularly on surfaces directly exposed to the sun. Later, these bronzed areas extend to the midribs, while the margins redden and the undersurface becomes yellowish-brown. Regions of intense red are usually the sites of heavy nymphal feeding. With further ageing, small black spots develop within each reddened section, and these may expand into appreciable areas of brownish-black dead tissue which eventually coalesce and extend between the larger veins. The necrosis, which may occur long before shedding of leaves, is associated with severe nymphal injury and is rarely encountered even on very susceptible varieties. More usually, leaves merely redden and are shed before necrotic areas have developed to any extent. Invariably, necrosis commences at a point equidistant from the adjacent larger veins, or at the margin of the leaves.

In addition to nymphal feeding, adult activity also influences the extent of leaf damage. The larger veins are punctured during feeding and oviposition; splitting and necrosis follow. The upper portions of the vein elongate more rapidly than the undersurfaces and the vein tips curl downwards. This vein curling proceeds at the same time as the marginal curling due to nymphal injury; crimping and buckling of the leaf results. When conditions are conducive to severe buckling and curling, the lamina of the leaves becomes harsh and brittle to the touch and the undersurfaces are discoloured by jassid excreta.

In varieties possessing jassid resistance, leaf injury is only encountered when the plants are grown in close proximity to heavily infested susceptible varieties; any symptoms that develop are due solely to adult feeding. In such instances, injury is confined to vein extremities.

In effect, jassid injury causes the premature ageing of the leaves and therefore leaf shedding is hastened. There is some evidence to suggest that only fully expanded leaves are shed; those which curl extensively and are restricted in their normal expansion as a result of jassid attack persist long after less damaged leaves have dropped from the plants. Thus the general picture of jassid injury is accentuated.

Injury cannot be attributed wholly to mechanical damage to the tissues, though splitting and distortion in the larger veins do occur. The more characteristic injury—namely, marginal curling and associated leaf discolouration—suggests the injection of some material by the insects whilst feeding, for relatively small numbers of nymphs can produce these symptoms. In contrast, large colonies of aphids, though ingesting cell sap in appreciable amounts, cannot be associated with a comparable amount of leaf distortion and discoloration; aphid damage is, in fact, far less than what would be expected from a population of only a few nymphal jassids.

When the jassid population is destroyed following applications of DDT, new growth will be produced that is entirely free from any evidence of curling or chlorosis, though the damage in the older leaves will persist. Normal leaf production may continue as long as jassids do not reinfest these leaves. This phenomenon suggests that toxic substances are injected by the feeding jassids but are localized in their effect. Overseas workers have previously recognized this fact. Parnell (1927) and Peat (1928) found that, by confining jassids in small containers attached to the cotton leaves, characteristic discolouration of the foliage occurred within that area of the lamina enclosed by the container, but was not ultimately transmitted outwards to the leaf margins. Workers in other crops, particularly Monteith and Hollowell (1929) in their studies of the potato leaf hopper in legumes, have advanced the theory that the insects inject some chemical or enzymic toxin into the tissues of their host plants.

Effect on the Plant and Crop.

Though the existence of an appreciable adult population at a time when the plants are still in the seedling stage may cause severe leaf damage and plant stunting, this form of injury is rarely experienced in an early planted crop and damage is seldom noticeable before the first formed bolls are set. Following the initial signs of jassid activity in early summer, and depending on conditions that favour jassid development, populations may increase rapidly at this time. Later the resultant drain on cell sap due to the high infestation, together with the reduced rate of plant development following increased boll formation, may be sufficient to arrest growth.

Marked differences in the effect on growth are noticeable between plants possessing varying degrees of susceptibility to jassid damage. The growth of highly susceptible plants may be completely suppressed, while those possessing some measure of resistance will continue growing. When plants are restricted in growth, the rate of square formation is materially reduced and flowering

occurs nearer to the extremities of the fruiting branches. Some squares are shed. This phenomenon may occur despite adequate soil moisture and can be likened to the effect on crop formation in early summer when soil moisture is inadequate.

Following the cessation of growth, flowering ceases and the undeveloped squares remain bunched within the stunted terminal, to be shed eventually as the plants age. The plants then present a severely curled and bunched appearance, while the petioles of the more severely damaged leaves stand at a greater angle than usual to the main stem. The premature shedding of the older leaves gives the plants an open appearance and reveals the vivid red colour of the stems and petioles.

Suppression of growth, following severe jassid damage, will materially affect the likelihood of profitable crop returns, particularly in the case of late planted crops. Early planted cotton may form a bottom and middle crop of bolls before jassid populations develop sufficiently to prevent further boll formation. Should this early-formed crop be destroyed by *Heliothis armigera* Hb., the possibility of a further crop developing during the remaining period of plant growth may be completely nullified by the larger jassid population that quickly develops on the resultant vegetative growth. Once plant development is retarded or totally suppressed by jassids, recovery is unlikely.

In addition to preventing further square formation, severe jassid populations by reducing plant vigour interfere with the normal development of squares and bolls already formed on the plants. Those squares forming bolls at a time of intense pest activity are rarely retained by the plant, while bolls already formed may either develop slowly or shrivel. Bolls that do develop may not open fully on reaching maturity, while the lint does not "foam" from the opened bracts as in the case of bolls maturing earlier.

The yield of seed cotton is materially affected following jassid attack and differences in yield between varieties are accentuated if planting is delayed and cropping coincides with the high jassid populations of midsummer.

Factors Governing the Extent of Injury.

As stated earlier, the density and dispersal of jassid populations and consequent injury to cotton are dependent on the availability of host plants, seasonal conditions, varieties grown, and crop growth. These major factors, either singly or collectively, are in turn dependent on circumstances which are to some extent often localized.

Early records in Queensland show that jassid damage was confined mainly to cotton grown on the red volcanic soils associated with monsoon forests. Ballard (1925 and 1928) stressed the association between these soils and jassid attack, attributing their connection to unhealthy plant growth due to a deficiency of phosphates and potash. The association of jassid damage in more recent

years with a number of soil types has largely discounted this postulate. In some years, very severe damage can be associated with alluvial sandy loams along watercourses, and with the brown clay loams of softwood and brigalow country. As plant growth reflects soil conditions, these must clearly be of some importance in influencing jassid damage. Sloan (1938) suggested this and stated that "the recent increase in the importance of the pest and the extension of the area subject to infestation are probably associated with soil changes brought about by cultivation and cropping practices."

In the case of crops grown on the red volcanic soils, the severe jassid damage experienced is due to an association of two circumstances. Firstly, these soils promote more vigorous plant growth when soil moisture is adequate than do the less fertile forest soils. Secondly, certain of the possible alternate hosts are particularly common on these better soils, which in many instances are closely associated with monsoon forests where winter conditions are less severe than those normally experienced on the lower lying land; these conditions favour pest survival over winter.

Other examples of soil conditions affecting plant growth, and hence influencing the likelihood of jassid attack, may be cited.

Plant competition for soil moisture during periods of poor supply often results in poor growth within fields, but along the edges of these fields or where gaps occur in the stand growth is more marked. In these latter areas, where plant competition is less acute, jassids find conditions more favourable to their development.

Soils planted to cotton for a number of years possess a high rate of nitrification during the early summer months, and good rains induce rapid vegetative growth resulting in large-leaved plants of a dark green colour; these are subject to jassid damage. Crops grown in Rhodes grass-cotton rotation, where the nitrate level is lower, produce slow-growing bushes which carry foliage of a pale green colour, and are less subject to jassid attack.

Adjacent areas of cotton grown on the same soil type but receiving distinctive cultural treatments may present totally different conditions for jassids. This was borne out in an experiment on irrigated and rain-grown cotton at Biloela Regional Experiment Station (Station Records). The variety Miller 39 was planted under irrigation in early October, while the rain-grown cotton could not be sown until early November. By mid-January, the early planted cotton was carrying an appreciable crop of bolls and the plants exhibited the pale leaf colour normally associated with cropping plants. On the other hand, the rain-grown crop had developed slowly and vegetative development was still in progress during February when the increasing jassid populations reached injurious levels. Further growth was suppressed by the jassid in the rain-grown crop, whereas injury was negligible on the irrigated block. Apparently, the physiological condition of the plants on the irrigated area was unfavourable for the pest and did not attract it from the adjacent heavily infested block.

Similarly, small areas within a field may not prove attractive to the pest while the remainder of the crop exhibits symptoms of intense jassid activity. The apparently "resistant" plants in such areas exhibit pale green, coriaceous leaves and possess an open type of growth.

In addition to the influence of soil and climatic conditions on pest populations, the variety of cotton grown will also influence the extent of damage experienced. Certain of the American Upland varieties introduced into Queensland are very subject to jassid damage and this factor has been taken into consideration when choosing varieties for the several cotton districts. Though a particular variety may show promise in a district or in a particular soil type, its degree of susceptibility to jassid injury has to be considered in those districts where jassids are known to constitute a problem. The use of varieties showing some measure of resistance to the pest offsets the risk of jassid injury in such areas, and the planting of the varieties Miller, Farm Relief and Stoneville in preference to the more susceptible varieties Triumph, New Mexico Acala and New Boykin was advocated. However, in years when conditions favour rapid development of the pest, all commercial varieties exhibit varying degrees of damage in jassid areas.

OTHER SPECIES DAMAGING COTTON.

Empoasca terra-reginae Paoli.

This jassid (Fig. 3) was recorded by Sloan (1938) from cotton in the Upper Burnett, Callide and Dawson Valleys, but the damage caused by it was not specified. Throughout these investigations specimens of *E. terra-reginae,* the tomato jassid, were often encountered, but seldom in numbers comparable with *E. maculata.* Their affinity for cotton is markedly less than that of the cotton jassid.

Appreciable populations of *E. terra-reginae* are more usually encountered on young cotton during spring and early summer months, when the harvesting of early summer crops or dry conditions have destroyed their normal hosts. Levels of population per plant may be high at this period. In extreme cases the plants wilt and suppression of growth may be followed by the eventual death of the seedling cotton. However, this latter condition is rarely encountered.

In contrast to *E. maculata,* nymphs and adults of *E. terra-reginae* may be encountered on any part of the plant, and it is not uncommon to find newly-emerged nymphs on the older leaves. Thus, where the insect has migrated from nearby crops (mostly solanaceous) in considerable numbers, the invaded cotton plants do not show injury commensurate with that encountered when smaller populations of *E. maculata* are present. The habit of total plant infestation by the tomato jassid, in contrast to the terminal infestation characteristic of *E. maculata,* results in less pronounced symptoms of plant injury.

Also in contrast to infestation by *E. maculata,* which is more or less evenly dispersed throughout a field, the migrating individuals of *E. terra-*

reginae spread relatively slowly beyond the point of initial entry, where plant growth may be checked to some extent. Despite an initial high level of population of *E. terra-reginae*, subsequent development of the insect is apparently restricted, and it is unusual for this insect to increase in numbers on cotton throughout the season.

Figure 3.
Adult of *Empoasca terra-reginae* (x30.)
[*Drawing by William Manley.*

The symptoms of injury associated with *E. terra-reginae* are confined to the older leaves of the plant and consist of "white-spotting" of the foliage. Nymphs are occasionally found on the undersurface of the terminal leaves, sometimes among those of *E. maculata*, but damage due to the two species could not be differentiated. However, older leaves which have supported large numbers of adults may approach a pale green or greenish-yellow colour, partly due to the presence of large numbers of the minute whitish areas representing individual

feeding punctures. Leaf curl is not associated with the presence of *E. terra-reginae*, and plants infested by this species do not present the characteristic injury symptoms of *E. maculata*.

All evidence suggests that cotton is not a major host of the tomato jassid and that the presence of appreciable populations of this species in a crop is fortuitous. The occasional individuals which may be found in any field of cotton may be regarded as remnants of a migrant population.

Empoasca alfalfae Evans.

This yellowish-green jassid is a pest of various legumes, and is commonly found on lucerne and members of the cowpea group. It has been recorded from cotton in the Gayndah and Ayr districts. In the former district, occasional plants were damaged; and the initial infestation arose as the result of forced migration from legumes in the vicinity.

The habits of this species appear to be very similar to those of *E. maculata*, and the nymphs are responsible for a similar form of leaf injury. Towards the margin of terminal leaves, pale green to chlorotic areas develop which are generally demarcated by the smaller leaf veins. Curling under of the leaf margins may also occur but owing to the few individuals implicated the acute symptoms of leaf injury could not be ascertained. No damage to the leaf veins, as a result of oviposition injury, was noticed.

THE PROBLEM OF CONTROL.

The frequent and serious losses occasioned by *E. maculata*, particularly in localities suited to its development, stress the need for methods of control. Though in itself a serious pest, the cotton jassid is only one of the hazards facing cotton growers. Losses from *Heliothis armigera* may, at times, far outweigh losses due to jassid attack, while even transcending the importance of these two pests, the dependence of cotton growers on suitable seasonal conditions for profitable crop returns must also be considered. The majority of crops in this State are dependent on rainfall for their entire development and growers would be unwise to consider methods of control, however efficient, that would be costly to apply, unless they were assured of adequate crop returns.

Evidence has been obtained that DDT dusts or sprays will effectively reduce jassid populations during the critical period of crop formation. Their use is dependent on the availability and maintenance of costly equipment which, on the present basis of cotton production, the grower can ill-afford. However, some scope for this form of control does exist in irrigated crops where joint control of jassids, *Heliothis* and other cotton pests is desirable.

Of more practical appeal to the cotton grower, though in itself not the complete answer to the problem, is the adoption of cultural measures which can be expected to reduce losses associated with jassid attack. The success of

these measures depends largely on the ability to plant crops early in the spring so that an appreciable number of bolls may develop before jassids become active. Though further fruiting may ultimately be depressed, an appreciable amount of seed cotton is harvested from those bolls formed before the late summer. However, dry weather or the ravages of *Heliothis* larvae often interfere with square and boll formation during the early summer months, and the advantage gained by early planting from the viewpoint of jassid control is often nullified. Crops planted in late November or early December are usually particularly susceptible to jassid injury, early boll formation coinciding with the occurrence of peak jassid populations. Should a dry spring have prevented earlier planting, the associated restriction to normal jassid development may enable such crops to produce sufficient bolls to ensure payable yields before jassid populations assume pest proportions.

From a purely cultural point of view, early planting is a desirable feature of cotton growing, for not only is the risk of jassid injury reduced but better overall yields can be expected. However, the dependence of early planting on uncertain weather conditions raises the necessity for a more reliable means of control.

The varietal characteristics of early maturity can be used to reduce losses from the pest, particularly when used to further enhance the advantages associated with early planting. Quick maturing varieties, such as Triumph, tend to escape the effects of jassid injury late in the season by forming the bulk of their crop early and so preventing vegetative development and conditions suited to the pest. Later maturing varieties often revert to rapid growth with the onset of summer rains.

Varieties also differ markedly in their susceptibility to the pest, and despite slower maturity some varieties may be grown with fair success while jassids are active in more susceptible crops. The variety Miller, though slower to mature than Triumph, exhibits some resistance to jassid development and is grown with moderate success in regions where Triumph suffers appreciable damage, particularly when sowing has been delayed until the early summer. This varietal reaction to jassid attack was exploited with some success for a number of years, particularly in those districts where jassids were more prevalent, but the value of this technique has waned as the pest has increased in importance.

It is obvious that the methods outlined above do not constitute a sure method of controlling this pest. However, the tolerance shown by certain commercial varieties does suggest that the exploitation of the tendency on the part of certain plants to resist jassid attack should provide a means of solving the problem. Two avenues of approach are open—firstly, the selection of strains exhibiting resistance to the pest from varieties already under cultivation; and secondly, the adoption of a cotton breeding programme to evolve resistant varieties suited to conditions in this State.

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APPENDIX.

HOST RANGES OF JASSID SPECIES.

The respective hosts of the several jassid species encountered during a search for the alternate hosts of *Empoasca maculata* :—

Species.	Feeding and Breeding.	Adult Feeding only.
Empoasca maculata Evans ..	Cotton(*Gossypium hirsutum* L.) *Sida corrugata* Lindl. .. *Abutilon* sp.	*Amaranthus viridis* L. *Chenopodium carinatum* R. Br. *Clerodendrum tomentosum* R. Br.
Empoasca terra-reginae Paoli ..	Potato (*Solanum tuberosum* L.) Tomato (*Lycopersicum esculentum* Mill.) Silver Beet (*Beta vulgaris* L. *var. Cicla* (L.) Moq.) Cotton .. .. *Trianthema portulacastrum* L. *T. decandra* L... .. .. *Amaranthus viridis* L. .. *Ricinis communis* L.	*Bidens pilosa* L. *Tribulus terrestris* L.
Empoasca alfalfae Evans ..	Poona Pea (*Vigna sinensis* (L.) Savi ex Hassk) *Pisum sativum* L. .. .. Lucerne (*Medicago sativa* L.) *Crotalaria* spp. .. .. Cotton	Potato
Thamnotettix argentata Evans	*Amaranthus viridis* L. ..	Potato Silver Beet *Trianthema decandra* L. *Crotalaria* spp. Cotton
Erythroneura sativae Evans ..	*Trianthema portulacastrum* L.	Silver Beet Beetroot (*Beta vulgaris* L. *var. crassa* Alef.) Lettuce (*Lactuca sativa* L.) Turnip (*Brassica rapa* L.) *Amaranthus viridis* L.
Empoasca pulcherrima Evans..	*Sida subspicata* F. Muell. ex Benth. *Sida rhombifolia* L.	Cotton
Empoasca malvae Evans ..	*Malva parviflora* L. .. .. *Abutilon* sp.	

RAT POPULATIONS IN CANEFIELDS DURING THE SPRING OF 1948

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SUMMARY.

Seasonal movements of rat population were observed and pregnancy records made. The data revealed a transient type of population consisting of small concentrations of survivors.

Weight-age curves of Melomys littoralis *drawn from data secured between* 1937 *and* 1948 *are presented.*

INTRODUCTION.

During the second half of 1948, rat infestations occurred in canefields in the Mackay district, particularly in scattered fields of the variety Q50, and in some of the far northern districts. Buzacott (1949) has recorded that rats, probably *Rattus conatus* Thomas, attacked young ratoon cane on river flats in the Mulgrave area of northern Queensland in early December. In the Seaforth area, near Mackay, the pests were prevalent in pineapple fields. These occurrences afforded opportunities for further population studies, in addition to the satisfactory testing of newer rat poisons reported previously (McDougall, 1949a and 1949b).

METHOD.

As well as by field observations and spot trapping from September, 1947, to January, 1949, basic data were obtained by tag and elimination trapping on standard grids in the concentrated populations available from June to December, 1948. Most of the work was done in the Mackay district, but some trapping by an experienced operator was made in the Mulgrave area during August and September, 1948.

Pregnancy records of suitable monthly samples were made, and pairs from the field were placed under observation in breeding cages. The ages of all specimens of *Rattus conatus* and *Melomys littoralis* Lonnberg were determined. These determinations were subjective, as previously described for *R. conatus* (McDougall, 1946). Though the body weight (to the nearest $\frac{1}{2}$ gm.) of *M. littoralis* is not statistically sound as a criterion of age estimates, it was of some assistance: the weight-age curves for this species have not been published previously and are given in the appendix.

RESULTS.

Checks by trapping in rat damaged cane before September showed that most populations had moved after attacking the crops. The largest *R. conatus* population encountered in cane during a September census was 30 ± 6 rats per acre covering 4·5 acres: most populations were scattered. In pineapple fields the heaviest pest population was 25± 5 rats per acre, and usually both *R. conatus* and *R. culmorum* T. & D. were present. Distribution was mainly as scattered colonies. From late October onwards, populations commenced to move and thin out, with an occasional temporary concentration. By January, 1949, the usual summer trapping difficulties due to movement and dying-off were encountered.

As there were no significant differences between population compositions, by age groups as percentages of monthly samples, from the central and northern districts, the combined data are given in Figure 1.

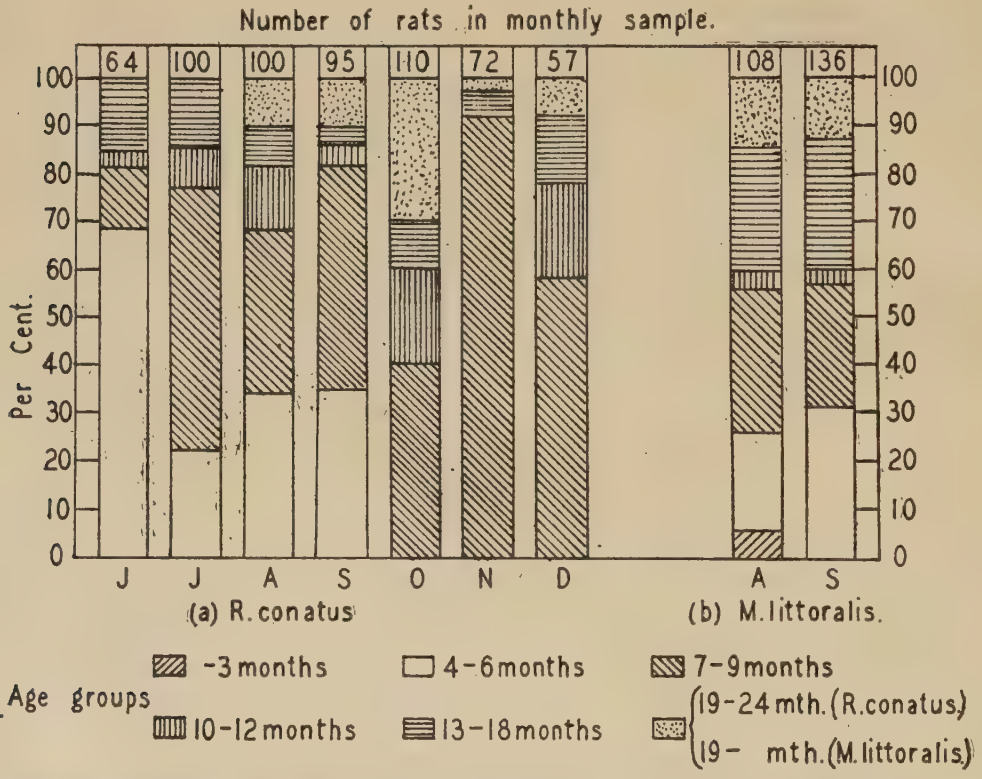

Figure 1.
Population composition by age groups as percentages of monthly samples from complete trapping out.

Only very light breeding by *R. conatus* occurred during the late spring of 1947 and in March and April, 1948. No pregnant specimen of this species was taken in the field during the second half of 1948, and no fruitful cage

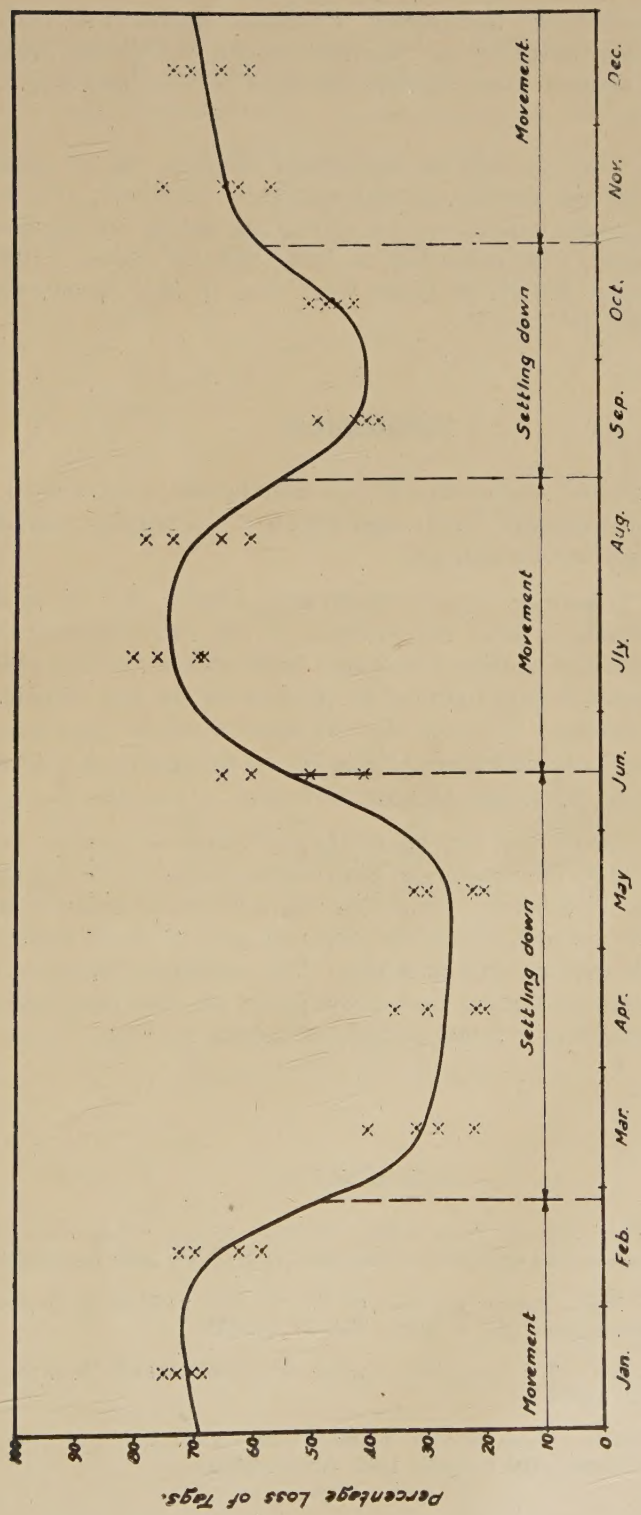

Figure 2.

Seasonal movement of rats illustrated by percentage loss of tags, on a monthly basis during 1937-41, from all finalised temporary grids. Many of the missing tags were recorded in other grids away from the original tagging sites.

breeding was recorded over this period. Pregnant females of *M. littoralis* were present in field populations during September to November, 1947, and April to June, 1948: an embryo count seldom exceeded 3, and breeding was never extensive.

Damage to cane by rats in the central districts was of mild nuisance value only, and did not warrant control measures. However, attacks on pine-apples were of economic importance, but during the spring settling-down period (Figure 2) the pests were controlled at little cost with loose 1 :1000 fluoro-acetate-wheat. Some 400 lb. of grain were used in this commercial project (McDougall, 1949b).

DISCUSSION.

General seasonal movements of rat populations were similar to those described earlier (McDougall, 1946), and Figure 2 is a graphic summary of the data on these important happenings.

Previously it has been stated (McDougall, 1949b), that in canefields and environs it is possible to have the presence of old rats without breeding, or breeding in the absence of older specimens: both these have been observed but are transient. Figure 1 gives data on the presence of old rats without breeding in Queensland canefields. In effect, this examination of the population demonstrates that the small concentrations of rats during the spring of 1948 were made possible by survival; there was no true upsurge.

There is no doubt that reports of the prevalence of rats in canefields in some seasons are due to the presence of populations similar to the type under discussion. Even the 1948 spring population was referred to topically as a rapid building up of rat numbers. From the economic and extension viewpoint these transient survivals require little attention. The maximum efforts in canefields could be confined to quietening pest activities in the few instances where an appreciable concentration is found actually attacking the crop.

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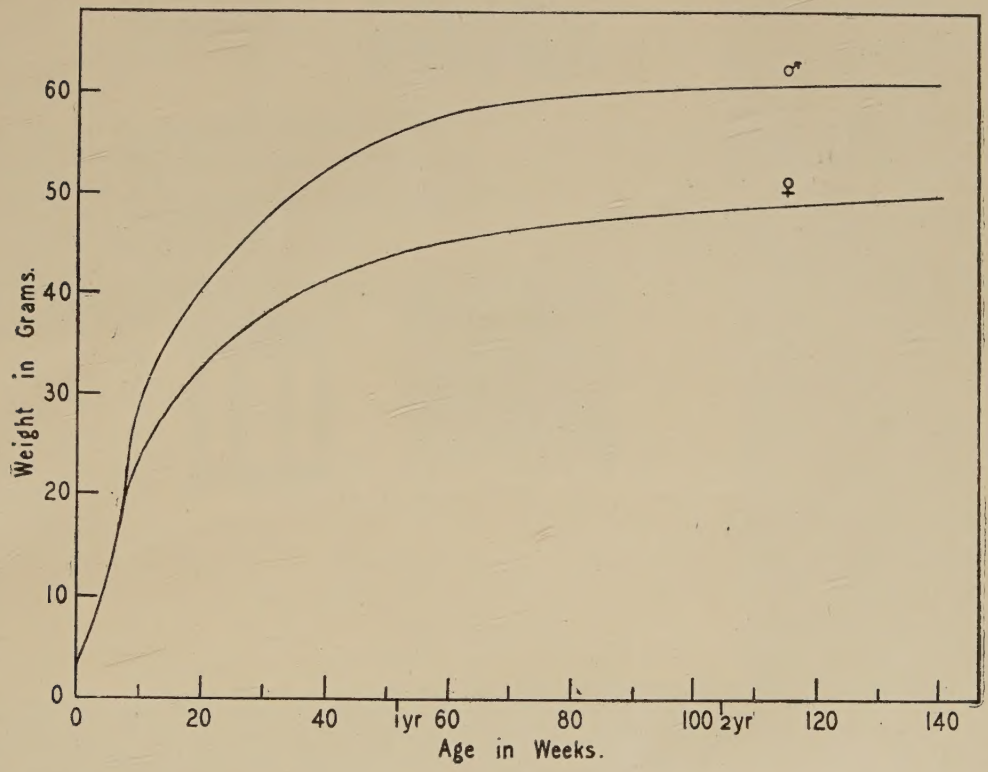
APPENDIX.

Weight-age curves of *Melomys littoralis*. Curves from spot weights of dormitory rats of known ages during the years 1937-41 and 1945-48.



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